

# Development and Testing of Non-Invasive BCI + FES/Robot System For Use in Motor Re-Learning After Stroke

Janis J Daly<sup>1,2</sup>, Roger Cheng<sup>1</sup>, Kenneth Hrovat<sup>1</sup>, Jean M Rogers<sup>1</sup>, Krisanne Litinas<sup>1</sup>, Mark E Dohring<sup>1</sup>

<sup>1</sup>Cognitive and Motor Learning Research Program, and Cleveland FES Center, DVA Medical Center; <sup>2</sup>Dept of Neurology, Case Western Reserve University, USA

## Abstract

We developed and tested a brain computer interface (BCI) system for use by stroke survivors for upper limb motor learning. A non-invasive BCI system was interfaced with a robot for shoulder/elbow movement training or an FES surface stimulator for wrist/hand training. Two healthy adults and five chronic stroke survivors were tested using the BCI + device system for motor learning feasibility. Measures were accuracy of brain signal control during imposed motor tasks: either shoulder/elbow or wrist/hand tasks that were 1) imagined or 2) attempted, as well as 3) imposed relaxation of muscles. Initial session accuracy for each condition was generated. Results showed that initial session accuracy was high for imagined and attempted tasks. Subjects had less accuracy with the relaxation task than with the imagined or attempted movement tasks. The brain signal accuracy was high enough to indicate the feasibility of using the BCI + FES/Robot for the purpose of motor learning. *Published: Proceedings of the 13<sup>th</sup> Annual Conference of the International Functional Electrical Stimulation Society "From Movement to Mind", 53 (Sept/2008; Freiburg, Germany); pp.200-202, Supplement 1, ISSN 0939-4990.*

## 1 Introduction and Methods

### 1.1 Purpose and Hypotheses

1.1.1. Brain signal control accuracy for imposed task of imagined or attempted movements of shoulder/elbow and a "relax" condition in both healthy adults and stroke survivors. In prior brain computer interface (BCI) uses, the brain signal was selected from among an array of motor and imaginary tasks, according to which task produced the most "usable" or "best" brain signal, regardless of whether the task had any bearing on the physical motor task at hand. This method of choosing the best brain signal is adequate when one is concerned only with turning on an environmental or communication device. However, when one is attempting to retrain brain signal for more normal drive of more normal motor function, the cognitive activity that generates the brain signal ideally should match the motor function that is being re-trained. There is a dearth of information suggesting that an imposed motor task or attempted motor task could generate a usable brain signal for BCI use after stroke. Therefore, we tested the usefulness of brain signal for shoulder/elbow and wrist/hand imposed motor tasks, in order to determine if the brain signal thus acquired, could be used in a BCI system for motor learning. *Hypothesis 1 was: healthy adults and stroke survivors could attain control of the brain signal by using imposed motor tasks.*

1.1.2. Initial session accuracy of brain signal control in stroke survivors for wrist and finger movements. One of the critical characteristics of a BCI brain training protocol is that high initial accuracy be achievable in brain signal control. This is important so that the patient can begin immediately to use the signal for re-training control of motor function, rather than spend weeks attempting to gain control of the signal. *Hypothesis 2 was: Stroke survivors will be*

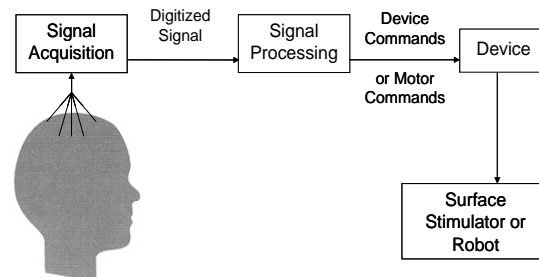
*able to attain sufficient accuracy of brain signal at initials sessions so that the brain signal can be used within a few weeks for motor-relearning purposes.*

### 1.2 Methods

1.2.2. Subjects. We enrolled 2 healthy adults, 2 stroke survivors with shoulder/elbow impairment, and 3 with wrist/hand impairment (>6 mos).

#### 1.2.3. Technology.

Figure 1: BCI System



Scalp EEG was acquired using a SynAmps<sup>2</sup> (Compumedics, El Paso, TX) amplifier system and an Electro-Cap (ECI, Eaton OH) with 58 monopolar channels referenced with linked earlobe electrodes. The signal was sampled at 250Hz and bandpass filtered from 0.1 to 60 Hz. We used the BCI2000 software (Wadsworth Research Lab; Albany, NY, USA) for the brain signal screening and brain signal training. We modified the BCI2000 graphical user interface and added an external trigger signal output capability using a Digital Output card added to the computer, configured to provide a trigger to activate the surface FES device. The robot was triggered through a network link. The robot assisted shoulder flexion and elbow extension in a horizontal plane (InMotion 2 Shoulder/Elbow Robot; MIT, Boston, MA, USA). A Universal External Control Unit (UECU; DVA FES Center, Cleveland, Oh,

USA) was configured by our team to provide surface FES. Robot or FES was triggered after the integrated brain signal passed a specified threshold. FES parameters were: 0-80Hz, 255 microsecs pulse width, and amplitude within a comfortable range. The surface electrodes were PALS (Alexgard, San Diego, CA).

**1.2.4. BCI screening.** During the screening session, brain signal was acquired while the subject attempted each of three types of tasks: 1) attempted motor task assigned; 2) imagined motor task assigned; and 3) relaxation task randomly alternated with either task 1 or 2. A 6-second sequence was used: 3 sec cue, 3 sec break. A frequency power analysis was conducted (3Hz bins, 0Hz to 30Hz). The optimal signal feature was selected according to the electrode/frequency combination yielding the highest explained variance ( $R^2$ ) between a given pair of conditions (e.g., attempted movement and relaxation).

**1.2.5. BCI task.** A computer monitor displayed the commands to move or to relax. The first training paradigm was attempted movement and relax task. A red rectangle at the top of the screen cued attempted movement. If the subject achieved and maintained heightened brain activity beyond the identified threshold, the rectangle color changed from red to green, signaling success. A red rectangle at the bottom of the screen cued the subject to relax. The top and bottom rectangles were presented in a random order, with a max 15secs allowed for each trial.

The second training paradigm was identical to the first, except that the top rectangle cued the imagine movement task. For attempted or imagined movement, if the subject reached the threshold brain signal activation, not only did the rectangle turn green, but also, either the robot (shoulder/elbow task) or the FES signal (wrist/hand task) was activated. Cues were presented in 10 sets, with attempted movement set alternated with imagined movement set (session duration=45min; 75 total attempted/imagined trials and 75 total relax trials/session; 9 sessions).

**1.2.6. Measures.** Brain signal accuracy was calculated as follows: correct target hits ÷ completed attempts; where, completed attempts = attempts for which one or the other target states was achieved in the allocated time; trials resulting in no outcome were recorded separately as errors.

## 2 Results

### 2.1. Brain signal control accuracy for imposed task of imagined or attempted movements of shoulder/elbow and a “relax” condition in both healthy adults and stroke survivors

Figure 2 (right half) shows that for two healthy adults, there was high brain signal accuracy for an imposed task of imagined shoulder/elbow reach

(>80% accuracy). For the imposed task of “relax the muscles”, the control subjects had a brain signal accuracy of 86% and 95%, respectively.

Figure 2 (left side of figure) shows that two stroke subjects were able to control brain signal activation during imagined shoulder/elbow movement at an accuracy rate of 97% and 84%, respectively. Their control of brain signal during the relax condition was lower at 38% and 49% accuracy, respectively (chance = 50%). These data are understandable in light of the visually observable difficulty that these two subjects had in achieving muscle deactivation of shoulder muscles.

Figure 3 shows that the two stroke survivors had 99% and 91% accuracy, respectively during the attempted shoulder/elbow task. Their accuracy was less for the relax condition when paired with the attempted movement task, shown in Figure 3 as 52% and 39%.

Figure 2: Brain Signal Accuracy - Imagined Movement

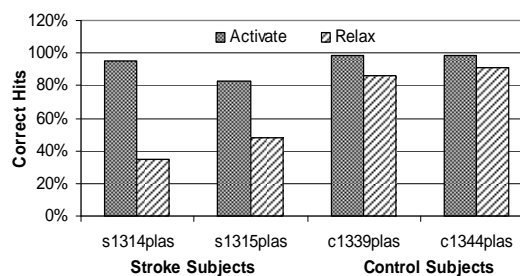
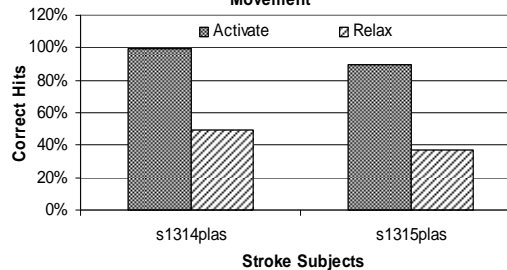


Figure 3: Brain Signal Accuracy - Attempted Movement



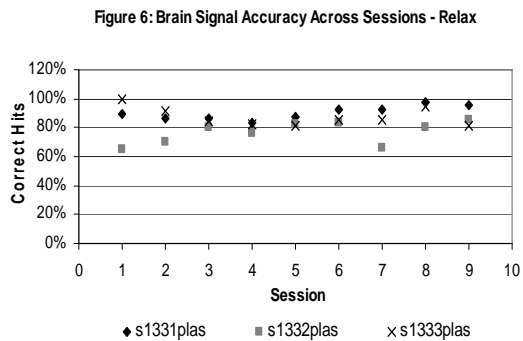
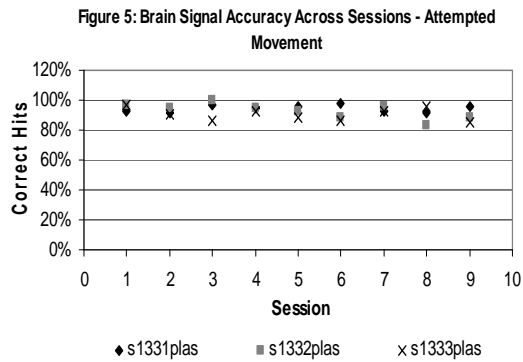
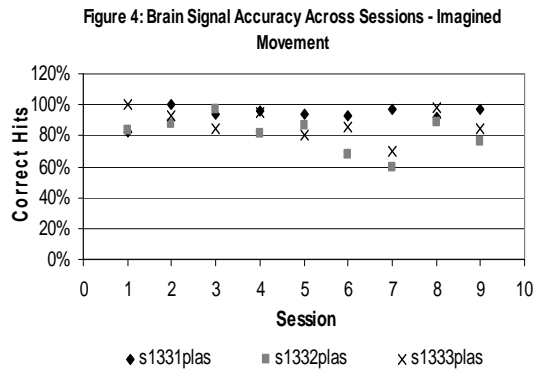
### 2.2. Initial session accuracy of brain signal control in stroke survivors for wrist and finger movements.

Figure 4 shows signal accuracy across 9 training sessions for three subjects performing the imagined wrist/hand task. Initial session accuracy (training session 1) for the imagined task was 99%, 84%; and 82%, for the three subjects, respectively. Brain signal accuracy was maintained across the subsequent sessions, sessions 2 - 9, above 80%, with the exception of sessions 6 and 7.

Figure 5 shows signal accuracy across 9 training sessions for three subjects performing the attempted wrist/hand task. Initial session accuracy (initial training sessions 1) for the attempted task was 99%, 97%, and 96%, respectively for the 3 subjects.

Accuracy was maintained across the subsequent sessions, sessions 2 – 9, above 80%.

During the imposed “relax” condition (Figure 6), initial session accuracy ranged from 65% to 100%, and was maintained at a range of 70% to 98% across sessions (except for two outliers at sessions 2 and 7).



### 3 Discussion and Conclusion

3.1. Discussion. Results showed that control subjects and stroke survivors could gain control of brain signal during performance of imposed shoulder/elbow and wrist/hand motor tasks and selected imposed relax tasks. This suggests that imposed mo-

tor tasks could be used in a non-invasive BCI system to indicate the user’s intent to perform the imposed task, which would be an important aspect of a potential BCI motor retraining system. These results were demonstrated for two types of motor tasks: a shoulder/elbow movement and a wrist/hand movement, as well as a motor relax task alternated with wrist/hand motor tasks.

However, the data showed that the two subjects performing the shoulder/elbow task both had great difficulty performing the relax task when the relax task was randomly presented with either the cue to attempt to move shoulder/elbow or the cue to imagine shoulder/elbow movement. These results were consistent with the visually observable difficulty that these subjects had in relaxing their shoulder muscles. These findings highlight the importance of retraining the ability to intentionally relax muscles as well as intentionally activate muscles, given that both are required for control of coordinated movements.

For this developmental study, results of brain signal accuracy were more encouraging for the wrist/hand task than for the shoulder/elbow task. This could have been due to subject differences, differences in the motor tasks, or differences imposed by the use of the FES device versus the robot.

Session 1 accuracy for the wrist/hand tasks was sufficiently high to suggest that for the three subjects in this study, brain signal control was available immediately for use in a motor retraining system. Overall, results suggested that the BCI + robot or BCI + FES system were feasible for stroke survivors to use.

3.2. Conclusion. Stroke survivors were able to gain control of brain signal for imposed imagined and attempted shoulder/elbow and wrist/hand tasks. Control of signal deactivation during the relax task was more difficult. Initial session accuracy was sufficiently high to be usable for motor learning for imposed wrist/hand imagined, attempted, and relax tasks.

## 4 Literature

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